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Development and performance evaluation of epoxy asphalt concrete modified with mineral fiber

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HIGHLIGHTS

- The epoxy asphalt concrete modified with mineral fiber (FEAC) was designed.
- The mineral fiber can increase raveling resistance and moisture susceptibility of FEAC.
- The mineral fiber can significantly improve crack resistance of FEAC at low temperature.
- FEAC has good resistance to fatigue cracking when fiber content is around 9%.

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ABSTRACT

In order to improve the performance of epoxy asphalt concrete (EAC), epoxy asphalt concrete modified with mineral fiber (FEAC) was designed. The properties of epoxy asphalt modified with mineral fiber (FEA) under different fiber contents and lengths were studied by viscosity test and direct tensile test, and the performance of FEAC with different fiber contents were evaluated through several laboratory experiments. The results showed that the mineral fiber with appropriate length and content can increase the viscosity of FEA, can improve tensile strength and fracture elongation of FEA, and can shorten the allowable construction time of FEAC. Moreover, the improvement effects of mineral fiber on permeability, friction and high temperature stability of FEAC is not significant, but use of mineral fiber can significantly increase raveling resistance and moisture susceptibility of FEAC. When the fiber content changes from 0% to 9%, the increasing amplitude of flexural strain at failure at −20 °C is 55.2%. It indicates that the addition of mineral fiber can significantly improve crack resistance of FEAC at low temperatures. Furthermore, FEAC has good resistance to fatigue cracking when fiber content is around 9%.

1. Introduction

Epoxy asphalt is a two-phase chemical system in which a thermosetting acid epoxy (continuous phase) is blended with petroleum asphalt (disperse phase). Before mixing, epoxy asphalt is typically stored in two separate components marked as A and B. Component A is the epoxy resin while Component B is the mixture of petroleum asphalt and curing agent. Once the two components are mixed, epoxy resin and curing agent begin an irreversible chemical reaction that increases the stiffness and strength of the mixture [1]. After curing, epoxy resin forms a three-dimensional continuous phase in which petroleum asphalt is dispersed. Such a mixture is not only tough but also elastic at typical pavement service temperatures up to 50 °C, providing high fatigue resistance [2–4]. Therefore, epoxy asphalt concrete (EAC), as a thermoset material consisting of epoxy asphalt and aggregate, does not soften as much as conventional asphalt concrete at high temperatures, has good resistance to aging and chemical attack and is impermeable to water and salts, in part due to its low void pavement design [5].

In the last two decades, EAC has been mainly used on numerous orthotropic bridge steel decks around the world [6–8]. Due to its superior durability, high temperature stability, fatigue resistance and waterproofness, efforts have also been spent to take advantage of the unique properties of EAC to solve several other difficult pavement challenges. Some examples of these additional applications of EAC include relatively thin dense-graded overlays on concrete bridge decks, durable open-graded surface mixtures on concrete bridge decks or roadways, and dense-graded mixtures for long-life roadway pavements [9,10]. However, the fracture elongation of epoxy asphalt is relatively low because of the high stiffness and strength, the epoxy asphalt is brittle at low temperatures and easily failed at a lower strain, which led to poor fracture performance of EAC. Under the comprehensive impact of increasing vehicle and harsh environmental load, crack becomes the main disease occurred in pavement using EAC, especially in extremely

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cold and high-latitude areas. Therefore, it is worthwhile to explore some approaches to modify EAC for better crack resistance and for a broader range of applicable traffic and climate conditions.

Among the modifiers of asphalt concrete, fibers have obtained more and more attention for their excellent improvement effects. Various types of fiber modifiers, such as cellulose fiber, polyester fiber and mineral fiber, have been widely used in different kinds of asphalt concrete and pavement. Punith et al. [11] evaluated the use and properties of open-graded friction course (OGFC) mixtures containing cellulose fibers. The draindown test showed that the addition of fiber reduced the potential for draindown in OGFC mixtures. Wu et al. [12] studied the rheological property of fiber modified asphalt by cone penetration test. It was found that fiber content and filler-asphalt ratio had significant effects on the softening point, penetration, viscosity and cone penetration of asphalt mortar. The reinforcement effect increased with fiber content increasing to a certain threshold, and the optimal fiber content was dependent on the fiber type and length. Moghadas et al. [13] proposed that addition of fibers to the asphalt concrete under a uniform distribution considerably increases the mechanical performance, which benefits all the corresponding fields involved such as repair and maintenance. Bordelon and Roesler [14] investigated the applications of fibers on a thin concrete overlay bonded to asphalt pavement. Palacios [15] identified that the stress absorbing membrane interlayer (SAMI) with addition of fiber can mitigate reflective cracking.

Fibers have been used in asphalt concrete for two main reasons: (1) to increase the toughness and crack resistance of asphalt concrete; and (2) to act as a stabilizer to prevent draindown of the asphalt binder [16]. Putman and Amirkhanian [17] analyzed the reinforcing and toughening effect of different kinds of fibers. Ye et al. [18,19] investigated the reinforcement mechanism of modified asphalt binder mixed with fiber. The results indicated that the elastic part of viscoelastic behaviors of asphalt binders was enhanced by the addition of fibers. In addition, through direct tensile test, Qian et al. [20] evaluated that addition of adequate polyester fiber can greatly enhance the tensile properties of the fiber reinforced asphalt, particularly in terms of fracture elongation. In cold regions, fibers were also used as additives to improve the fracture performance of asphalt concrete, to reduce or eliminate the occurrence and expansion of the crack [21,22].

There have been many studies about addition of fibers to the asphalt concrete like above, but most of them are focusing on thermoplastic material, few studies for thermoset material, such as EAC. Considering the reinforcing and toughening effect of fibers, and excellent properties of EAC widely used in bridge and roadway construction, it is worthwhile to investigate the properties and performance of epoxy asphalt concrete modified with fibers, especially in terms of crack resistance at low temperatures. This paper presents results of such a study.

2. Objective

This paper presents a laboratory study to evaluate the properties of epoxy asphalt modified with mineral fiber (FEA) under different fiber contents and lengths, and the performance of epoxy asphalt concrete modified with mineral fiber (FEAC) under different fiber contents were evaluated through several laboratory experiments.

3. Experimental design

3.1. Materials

The epoxy asphalt used in this work was obtained from a U.S. manufacturer who had supplied the same material to many steel bridge deck and roadway paving projects in China and the U.S., and the basic properties of the epoxy asphalt and its two components are presented in Table 1. The basalt aggregate with a nominal maximum size of 9.5 mm and gradation shown on Table 2 was produced from a basalt quarry located in Jiangsu Province, China, has a density of 2.65 g/m^3 and compressive strength of 145 MPa.

Considering the better effect on fracture performance improvement compared to cellulose fiber and polyester fiber [23–25], mineral fiber (basalt fiber) was selected as the additive to FEAC in this study. The mineral fiber was produced by the Jiangsu Tianlong Continuous Basalt Fiber Hi-Tech Co. Ltd., its properties is shown in Table 3 (provided by the manufacturer).

3.2. Fiber content and length

The reinforcement effect of modified asphalt binder mixed with fiber is closely related to fiber content and length [12,13,17]. To find out the best fiber content and length, viscosity test and direct tensile test of FEA were conducted. Five mineral fiber contents (by weight of epoxy asphalt), namely 0%, 3%, 6%, 9% and 12% and three mineral fiber lengths including 2 mm, 5 mm and 8 mm were considered. The fiber content of 0% represents the epoxy asphalt without mineral fiber.

Viscosity of FEA is not an absolute property. However, it may exhibit non-Newtonian behavior of FEA, and it decides the allowable construction time (the longest time from mixing epoxy asphalt's two components to the beginning of paving asphalt concrete in construction) of FEAC [26]. Viscosity test was carried out using a Brookfield viscometer in accordance with ASTM D 4402. Before the test, the prepared mineral fiber was added to the Component A of epoxy asphalt when Component A was heated to 87 °C in an oven. Then a mixer with a rate of 400 rpm (for less than 2 min) was used to mix mineral fibers and Component A, and blended the produced mixture with Component B when Component B was heated to 133 °C, so the samples of FEA in viscosity test were done. The fixed mix ratio of Component A and Component B was 1:2.45.

Direct tensile test was conducted on direct tension tester by Instron Company in accordance with ASTM D 638. The test was controlled at displacement rate of 500 mm/min. The key of this paper was low temperature performance of FEA, hence the test temperature was set at −20 °C. The test was repeated three times at each mineral fiber content and length.

The viscosity test results are shown in Fig. 1. From Fig. 1 it can be seen that the viscosity of FEA increases with increasing time, and start to increase quickly when the viscosity exceeds around 1000 mPa s. Moreover, mineral fiber increases the viscosity of FEA, and the effect increases with increasing fiber content. In addition, the FEAC is thermoset material, after curing completely, the FEAC will become too hard to pave and compact. The curing speed of FEAC is closely related to its viscosity growth rate. Therefore, the viscosity growth rate is very important to FEAC. In the construction of FEAC, the allowable construction time, depends upon the viscosity of FEA, is commonly used in China. The allowable construction time is the time of FEA's viscosity from 0 to 1000 mPa s [26]. The time from mixing epoxy asphalt's two components to the beginning of paving asphalt concrete must be less than the allowable construction time. The mineral fiber can increase the viscosity of

Table 1
Properties of epoxy asphalt.

Property	Value	Test method
Epoxy resin (Component A)		
Viscosity at 23 °C, Pa s	11–15	ASTM D 445
Epoxide equivalent weight	182–292	ASTM D 1652
Color, Gardner, max	4	ASTM D 1544
Moisture content, % max	0.05	ASTM D 1744
Flash point, Cleveland open cup, °C, min	200	ASTM D 92
Specific gravity at 23 °C	1.16–1.17	ASTM D 1475
Appearance	Transparent amber	Visual
Mixture of petroleum asphalt and curing agent (Component B)		
Viscosity at 100 °C, Pa s, min	0.14	ASTM D 2983
Acid Value, mg KOH/g	40–60	ASTM D 664
Flash point, Cleveland open cup, °C, min	200	ASTM D 92
Specific gravity at 23 °C	0.98–1.02	ASTM D 1475
Color	Black	Visual
Epoxy asphalt (the mix ratio of Component A and Component B is 1:2.45)		
Time (viscosity from 0 to 1000 mPa s), min, min	50	ASTM D 4402
Tensile strength at 23 °C, MPa, min	1.52	ASTM D 638
Fracture elongation at 23 °C, %, min	190	ASTM D 638